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PERFORMANCE OF THE TSUNAMI (II) MACROCELLULAR FIELD TRIAL SYSTEM USING A DYNAMIC INTERFERENCE SOURCE

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Abstract - The TSUNAMI (II) project has been an investigation into the application of adaptive antenna technology for use in future generation mobile communications systems. The key aims of the project were to investigate the complexity versus increase in system capacity and coverage extension that can be achieved over the existing, non-adaptive networks. May 1998 saw the completion of an 8 month field trial, covering both macrocellular and microcellular trials. These investigations were performed at the Orange Testbed in Bristol, U.K., using a modified DCS-1800 base station. In this paper are presented a subset of the macrocellular field trial results, obtained using spatial and temporal reference beamforming (TRB and SRB) in the presence of a moving, deliberate interference source. The results presented show the comparative performance of several selected adaptive antenna algorithms used by the TSUNAMI (II) testbed. The results of these trials demonstrate how the interference source and chosen algorithm's ability to track wanted to unwanted users influences the overall performance of the Adaptive Antenna Base Station (AA-BSS).

I. THE TSUNAMI (II) PROJECT

The TSUNAMI (II) (Technology in Smart antennas for UNiversal Advanced Mobile Infrastructure - Part 2) project was set-up under the EU ACTS research programme and was the extension of the RACE TSUNAMI project.

The project is an investigation into the use of adaptive antenna systems for use in third generation networks. As such, its key aims were to demonstrate the capacity increase and coverage extension [1] that can be gained through the use of spatial diversity in an Adaptive Antenna Base Station Subsystem (AA-BSS) for use in a mixed cell environment. The adaptive antenna system operates via filtering in the spatial domain, through modification of the transmitted or received antenna array signals with respect to time, frequency and spatial response.

The employment of beam forming algorithms allows a narrow beam pattern to be produced from the adaptive array which can be steered towards or *track* the desired user. In addition, some algorithms allow spatial nulls to be introduced into the beam pattern towards any sources of interference or unwanted users occupying the same channel bandwidth, ideally cancelling out the effects of their presence. Alternatively some algorithms are used to maximise the effective signal to identifiable noise. The use of these algorithms can be shown to give a marked improvement of antenna performance over single element (sectored) antenna performance and hence lead to a potential capacity enhancement within the network.

II. MACROCELLULAR FIELD TRIAL DEPLOYMENT

The TSUNAMI (II) field trial system includes a modified DCS-1800 basestation system, supplied by Motorola, to which an 8-element adaptive antenna sub-system has been retro-fitted. The transmit and receive antenna system was designed and constructed by CASA, Spain [2]. The antenna array for the macrocellular trials was mounted at a height of 27m on a tower at the testbed site. The boresight direction of the array is nominally due East, but is subject to

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misalignment errors at installation (these are thought to be within ±1° for the macrocellular installation).

TSUNAMI (II) Adaptive Algorithms

In order for systems to benefit from the potential increases in gain from an adaptive antenna, it is important that the employed beamforming algorithms can accurately track the position of the wanted mobile station (MS) from any unwanted interference sources. The TSUNAMI (II) field trial system was capable of using any one of a set 5 beamforming algorithms, in addition to single element mode and manual beam pattern control [2]. However, for the tests performed for this section of the trials, only the 'intelligent[1]' beamforming algorithms were used, with the single element case used as a baseline performance level. The algorithms used were:

- **Spatial Reference Beamforming using MUSIC (MUSIC):** Here MUSIC is employed as a direction finding (DF) method in order to detect the number of signals present, and also estimate their direction of arrival (DOA). This DOA information is then used to synthesise a beam steered at the wanted signal and nulls in the direction of the other signals (usually interference). A Kalman filter is also used to enhance the tracking process.

- **Optimum Combining (OPT):** The DCS-1800 training codes are used as a reference signal to compute the Wiener optimum weight vector. This vector minimises the power of an error signal, which is defined as the difference between the beamformer output and the reference signal. This is also known as temporal reference beamforming.

- **Temporal Reference Beamforming Grid of Beams (AUC).** This algorithm was developed by the University of Aalborg [3]. It operates by using the DCS-1800 training sequence in the uplink received burst to form an estimate of the channel impulse response from the mobile to each array element. These impulse responses are then used to select the direction, from a grid of 22 beams, which will maximise the energy of the wanted signal. The same look direction is used for the downlink.

[1] Algorithm 'intelligence' refers to the ability to differentiate between a wanted and unwanted user's signal.

III. MOVING MOBILE WITH MOVING INTERFERENCE SOURCE

The tests analysed in this section of the document are part of the macrocellular field trials completed with a moving interference source. The interference source for these experiments was a signal generator and an RF amplifier located in a test vehicle. Also in the same vehicle was an additional DCS 1800 handset connected to a GPS receiver, with a PC running the Ericsson TEst Mobile System (TEMS) software. This handset was in idle mode, receiving the TSUNAMI (II) BCCH carrier. From the TEMS log file recorded in the interference test vehicle, the GPS position of the interferer and the current basestation frame number can be extracted, thus enabling the synchronisation of the interference data with the basestation and beamformer data.

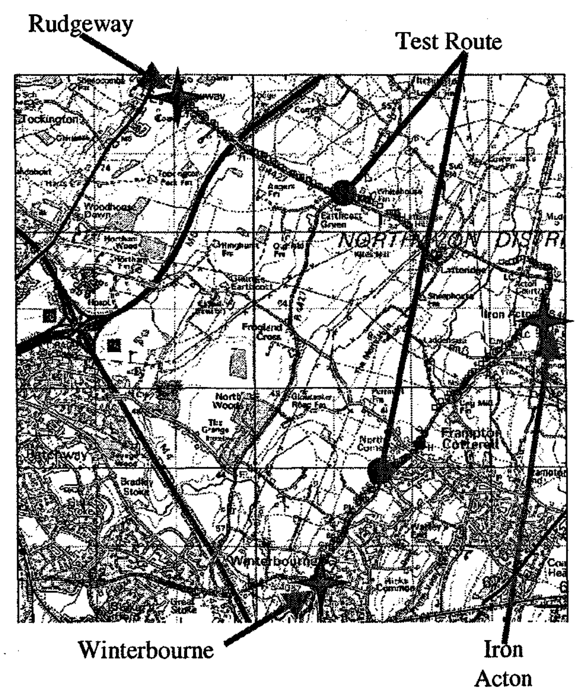

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Figure 1 Test Route

For the trials analysed, the MS and the interference source test vehicles are driven along the same test route, but in opposite directions to each other. Figure 1 shows this route which was taken between Winterbourne and Rudgeway, via Iron Acton. This represents a total angular region of approximately 90° of the 120° sector covered. As the two signal sources are travelling in opposite directions, the relative angular separation between them can vary from 0° to approximately 90°. The interference was a modulated (GMSK) signal source and was set in level to be *approximately* equal to that of the MS[2] when both were stationary in a layby in Winterbourne.

DOA Tracking and Algorithm SINR Performance

The importance of the beamforming algorithms to be able to correctly ascertain the wanted user's DOA relies on the accurate calibration of the uplink receiver chains, and the manner in which the algorithm discriminates between a wanted and an unwanted signal source. With both the MS and the interference source being mobile, it can be expected that the method of wanted signal identification will be even more pertinent, as the channels of both the MS and the interference will be subject to fluctuations.

Table 1 shows the RMS and standard deviation of the DOA error for the tests performed. In the case of the MUSIC algorithm, this shows the track of the wanted interference source (MS) as well as the interference source itself (Interference).

Estimates of the beamformer SINR performance were obtained from the measurements performed by the BSS during the DCS 1800 IDLE frames. For the trials analysed in this paper, the beamformer was 'forced' to measure IDLE frames at regular intervals throughout the tests. Thus, by relating each IDLE frame measurement with an adjacent ACTIVE frame measurement, estimates of the element and beamformer output SINR can be made for all the trials.

All the trials analysed have varying input SINRs, which typically range from -10dB to +30dB. The mean SINR gains over the trials analysed are displayed in Table 2, where it can be seen that the MUSIC and AUC algorithm trials have performed the best. The reason for the lower beamformer gain from the Optimal Combining algorithm was that for a significant portion of the test the algorithm chose the wanted user DOA incorrectly.

Similarly, the MUSIC algorithm occasionally became confused and at these points would mistakenly assigned the wanted user as an interferer and thus attempts to null it. Consequently, the resulting beamformer SINR gain is negative. This is further emphasised in Figure 2, where the estimated beamformer SINR gain is plotted against the relative DOA of the MS and the interferer. As can be seen, the beamformer gain is *approximately* constant apart from the angular region where the two signal sources are separated by less than 10°.

Call Qualities

The call qualities during the field trials provide a clear indication upon the performance of each algorithm. However, it is important to note that, as the interferer was also dynamic during the trials analysed in this section, the conditions faced will not be identical from test to test. Figure 3 shows the uplink and downlink quality outage curves for the tests analysed in this section. Also shown are the GPS DOA measurement reports of the wanted user that are used in calculating the distributions shown. This indicates the proportion of the test that is included in the evaluation of the quality distributions.

From Figure 3 it is clear that the MUSIC and AUC algorithms have performed better than the Optimal Combining algorithm, with almost 40% of their uplink measurements being at the highest call quality compared to less than 20% for Optimal Combining and Single Element tests. The difference between the downlink qualities is principally due to the considerably higher power transmitted when all eight array elements are utilised.

Observations on Dynamic Interference Source Trials

In this paper, analysis has been performed on a selection of the TSUNAMI (II) field trials involving the use of a dynamic interferer. The interference source was a GMSK modulated source set to a comparable transmitter power level to that of the MS. The interference source was located in a second test vehicle which was driven along the same test route as the MS but driven in the opposite direction.

Despite the difficulties in comparing the algorithms directly in this test scenario, it has been ascertained that the MUSIC and AUC algorithms performed best. Over the whole test route their mean beamformer SINR gains were approximately +10dB, with the Optimal Combining trial achieving a gain of less than +7dB.

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[2] Handset power control was disabled for all of these experiments to prevent unwanted variations in transmit power for these experiments.

The reason for this reduction in performance is largely due to the implementation of the algorithm used on the testbed. The basic form of the algorithm has been shown to suffer from SINR degradation at high C/I due to noise and interference enhancement at the combiner output. This problem is due to imperfect correlation between the training sequence and the received modulated signal, which is inevitable in any practical system. A beam space method could be used to mitigate this effect by matching the number of degrees of freedom available to the combiner to the number of signals present. This technique would improve the performance but relies on accurate estimation of the number of signals present.

In the region where the angular separation of the two signal sources is less than approximately 10°, the beamformer gain is reduced. In the case of the MUSIC algorithm, this region has little gain at all as the tracking algorithm is unable to correctly resolve the wanted and unwanted signal sources. However, for the AUC algorithm, the gain in this region increases with relative DOA. This corresponds to the shape of the main beam of the uniformly weighted array as this typically occupies a ±10° region about its look direction.

In theory, the MUSIC based algorithm should provide a higher C/I gain than the AUC algorithm, as it attempts to place a null on the interference source. However, from the mean beamformer gains presented in this section, there is no significant difference between them. This suggests that in the field trials, achieving accurate or deep nulls was not possible. However, it is difficult to isolate a single cause for this.

IV. ACKNOWLEDGEMENTS

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	Optimal Combining	MUSIC -MS	MUSIC - Interference	AUC algorithm
Mean	+1.0	+1.4	+3.3	+0.2
RMS	14.6	2.8	6.0	8.1
STD	14.6	2.4	5.3	8.1

Table 1: DOA Error Statistics

	Single Element	OPT	MUSIC	AUC
Mean SINR gain over trial	-1.0 dB	+6.7 dB	+10.1 dB	+9.7 dB

Table 2 Mean SINR Gains for Tests

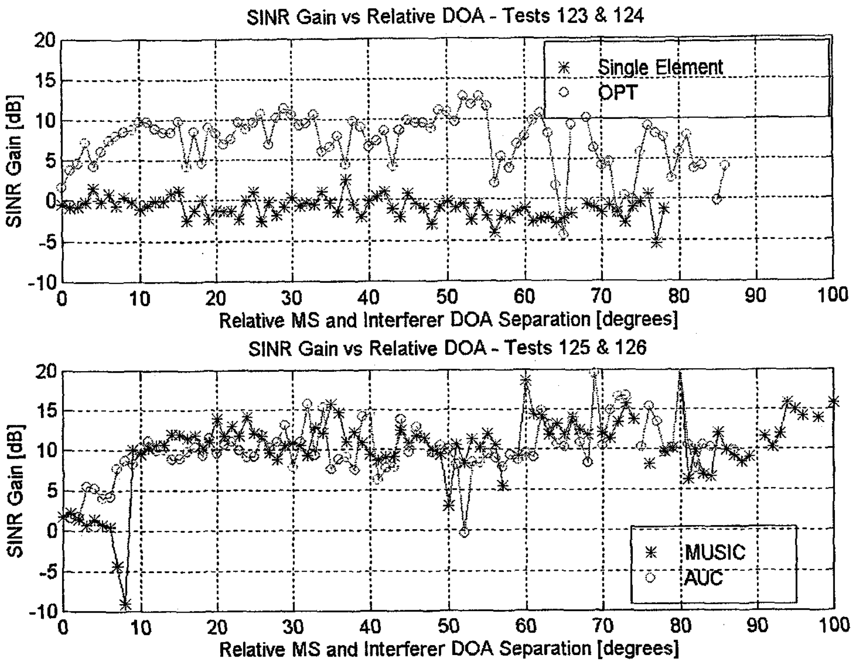

Figure 2 Estimated Beamformer SINR Gain vs Relative DOA

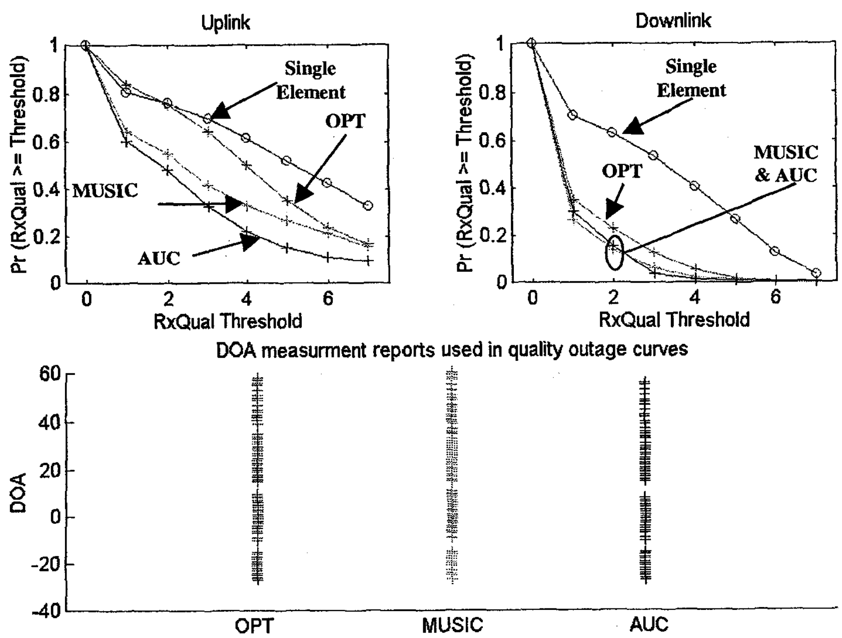

Figure 3 Call Quality Outage Curves for Various Algorithms